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Proc. of Int. Conf. on Advances in Mechanical Engineering, AETAME

Performance and Emissions Characteristics of a C.I. Engine Fuelled with Different Blends of Biodiesel Derived from Waste Mustard Oil

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***Abstract*— In this research work, waste mustard biodiesel-diesel fuel blends as alternative fuels for diesel engines were studied. An experimental investigation has been carried out to evaluate the performance and emission characteristics of a diesel engine fuelled with waste mustard biodiesel-diesel blends (10%, 15% and 20%) and important fuel properties have also been determined. The performance parameters analyzed include brake power, brake thermal efficiency, brake specific fuel consumption, and exhaust gas temperature whereas exhaust emissions include unburnt hydrocarbons (UHC), carbon monoxide (CO) and oxides of nitrogen (NO_x). The results of the experiment in each case were compared with baseline data of diesel fuel. Significant improvements have been observed in the performance parameters of the engine as well as exhaust emissions. The waste mustard biodiesel-diesel fuel blends were tested in a single cylinder direct injection diesel engine. Engine performance and exhaust emissions were measured while the engine running at no, part and full load condition. This paper investigates the scope of utilizing waste mustard oil blends with diesel fuel. It concluded that B10 blend of waste mustard biodiesel act as best alternative fuel among all tested fuel at full load condition. The objective of the present research was to explore technical feasibility of waste mustard oil in direct injection C.I. engine without any substantial modifications in the engine design..**

***Index Terms*— Waste mustard oil, Biodiesel, Transesterification, Performance characteristics, Emission characteristics, C.I. engine**

I. INTRODUCTION

Decline in fossil fuel resources along with high crude oil prices generated attention towards the development of fuel from alternate sources [1,2]. Such fuel should be economically attractive and performance competent in order to replace the fossil fuel [3]. Biodiesel has emerged as a clean fuel. Biodiesel offers a very promising alternative to diesel oil since they are renewable and have similar properties [4]. Biodiesel can be prepared from a variety of feedstocks such as vegetable oils or animal fats [4]. Vegetable oils may be edible or non edible. Use of non edible vegetable oils is recommended by Ministry of non-renewable energy (MNRE), India. Also, throughout the world, there is an enormous amount of waste lipids generated from restaurants and food shops posing a challenge for their storage and proper disposal in the environment. Reuse of these

DOI: 02.AETAME.2013.4.23

oils not only helps in its management but also lowers the production cost of biodiesel. Biowaste cooking oils thus opened a good opportunity to study its suitability to produce biodiesel. Waste mustard oil is easily available in abundance in Indian sub-continent and can be easily collected from any local restaurant [5]. Biodiesel can be fuelled into a C.I. engine upto a specified blending with the mineral diesel without changing the existing design of the engine cylinder [3]. The problem lies in the high viscosity of the biowaste cooking oils [1,6]. Transesterification process can be used as a handy tool to reduce the viscosity of the waste oil [1]. Biodiesel can be prepared mainly by four methods i.e. transesterification, pyrolysis, micro-emulsion technique or can be used by direct blending [7].
An experimental study was also carried out to examine fuel properties, performance and emissions of different blends of waste mustard biodiesel in comparison to diesel fuel. Performance characteristics like brake power, brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature and emission characteristics like unburnt hydrocarbons, carbon monoxide and oxides of nitrogen of biodiesel blended fuelled C.I. engine were evaluated and compared with that by fuelling diesel while the engine running at no, part and full load condition. The objectives of this experimental study are to assess performance and emission characteristics of a diesel engine when tested with selected fuels and compared with diesel as a reference fuel.

II. MATERIALS AND METHOD

A. Materials

The waste mustard oil used in this study was collected from a local snacks shop in Patiala, Punjab, India. The biodiesel from the waste mustard oil was extracted at Mechanical Engineering Research and Development Organization, Ludhiana, Punjab, India. The mineral diesel was bought from a local filling station in Patiala, Punjab, India.
Biodiesel was prepared from waste mustard oil by alkali catalysed transesterification. KOH was used as the catalyst amounting 1.5% on mass basis and 20% methanol was treated with the waste mustard oil. The water bath shaker was used for the base catalysed transesterification process.

B. Properties of biodiesel

The properties of the mineral diesel and mineral biodiesel are tabulated in the table I. These properties are compared with ASTM standard. The properties were tested at Mechanical Engineering Research and Development organization, Ludhiana, India & Thapar Research & Development centre, Patiala, India

TABLE I COMPARATIVE PROPERTIES OF THE MINERAL DIESEL AND MINERAL BIODIESEL

Property of oil	ASTM Standard	Diesel	Waste mustard biodiesel
Density (30^0C), kg/m^3	-	850	859.57
Kinematic Viscosity, cSt	<5	2.049	3.575
FFA, %	<2.5	-	0.1974
Carbon residue, % (m/m)	<0.05	0.0214	0.0138
Cloud point, ^{0}C	-3 to 12	-12	4
Pour Point, ^{0}C	-15 to 10	-16	-12
Flash point, ^{0}C	>130	60	145
Fire point, ^{0}C	>53	67	150
Calorific value, kJ/kg	>33000	42000	39542.98

C. Experimentation set up

The engine tests were conducted on single cylinder, direct injection water cooled compression ignition engine to evaluate performance of a 3.5 kW diesel engine at three different load conditions i.e. no (0 kg), part (2-4 kg) and full load (6 kg) at 12 compression ratio. The engine has a hemispherical combustion chamber with overhead valves operated through push rods. Cooling of the engine was accomplished by circulating water through the jackets of the engine block and cylinder head. The specifications of the C.I. engine are summarized in table II.
CO and NOx were estimated with the help of flue gas analyser whereas Horiba analyser was used to measure the amount of the unburnt hydrocarbons.The experimental data generated were calculated and presented through appropriate graphs. Performance and emission tests were conducted on various biodiesel blends in

order to optimize the blend concentration for small term usage in CI engines. This test was aimed at optimizing the concentration of ester in the biodiesel blends to be used for one hour engine operation. To achieve this, three samples of waste mustard biodiesel-diesel blends i.e. B10, B15 and B20 were prepared to be fuelled into variable compression diesel engine. The optimum blend was found out from the graph based on maximum thermal efficiency and other engine emission characteristics.

TABLE II. SPECIFICATIONS OF THE ENGINE

Feature	Description
Make and Model	Kirloskar, TV1
Type of engine	4 stroke, Variable compression diesel engine
No. of cylinders	Single cylinder
Cooling media	Water cooled
Rated capacity	3.5 kW @ 1500 RPM
Cylinder diameter	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Compression ratio	12:1-18:1
Orifice diameter	20 mm
Dynamometer	Eddy current dynamometer
Dynamometer arm length	145 mm

III. RESULTS AND DISCUSSION

A. *Performance characteristics*

Brake power(BP). Fig. 1 illustrates the variation in brake power with the change in load. At no load conditions, the brake power of diesel, B10, B15 and B20 was almost same. As the load increased, BP of the engine started to be lesser for biodiesel blends as compared to diesel. The decrease in BP was due to the lower heating value of biodiesel [3,8,9]. Maximum brake power was obtained in fuelling diesel in comparison to B10, B15 and B20 respectively. At full load conditions, the brake power produced by B10 is 3.74%, B15 is 6.9% and B20 was 10.1% less than diesel.

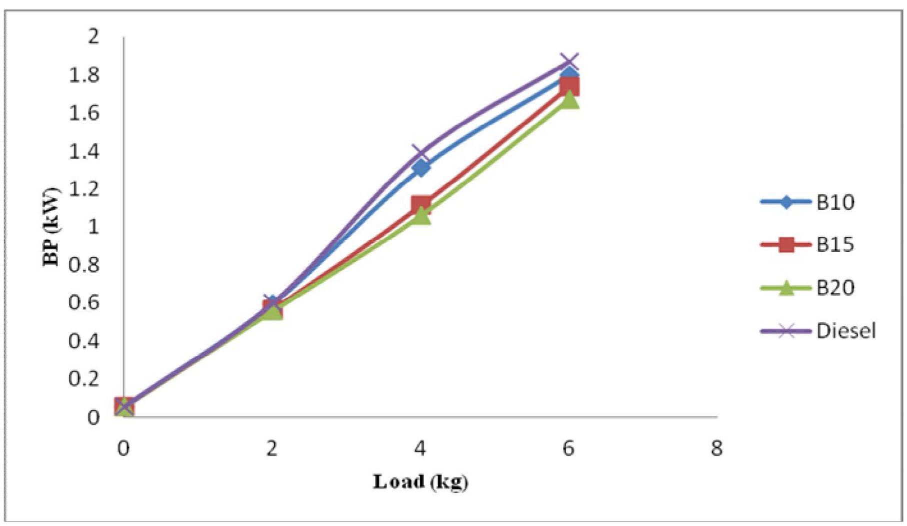

Figure 1. Variation in brake power with the change in load

Brake specific fuel consumption (BSFC). Fig. 2 illustrates the variation in brake specific fuel consumption with the change in load. At low load conditions, BSFC of diesel was the least. BSFC of B10, B15 and B20 was more than that of diesel respectively. After that the brake specific fuel consumption decreased continuously with increase in load. But BSFC in case of waste mustard biodiesel remained more than that of diesel. It was due to lower energy content of waste mustard biodiesel [3,8,9]. At part load conditions, BSFC

of B10 and diesel was almost same whereas BSFC of B15 was 23.4%, B20 was 28.05% more than that of diesel. At full load conditions, BSFC of B10 was 10.9%, B15 was 18.23%, B20 was 25.5% more than that of diesel.

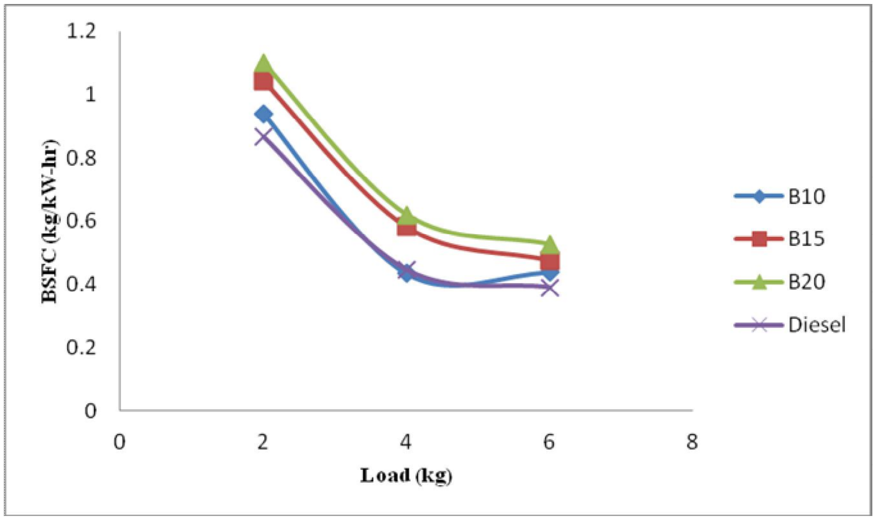

Figure 2. Variation in brake specific fuel consumption with the change in load

Brake thermal efficiency(BTE). Fig. 3 illustrates the variation in brake thermal efficiency with the change in load. At no load condition, brake thermal efficiency of B10, B15, B20 and diesel was same. As the load on the engine increased, brake thermal efficiency increased due to the fact that brake thermal efficiency is the function of brake power. At part load conditions, the brake thermal efficiency of B10 was more than diesel because mass of B10 supplied was 19.35% less than that of diesel and calorific value of B10 was also less than that of diesel. Brake thermal efficiency of B15 and B20 was almost same at part loads and was 16.67% lesser than diesel. At full load conditions, brake thermal efficiency of B10, B15 and B20 was almost same but was lesser than that of diesel.

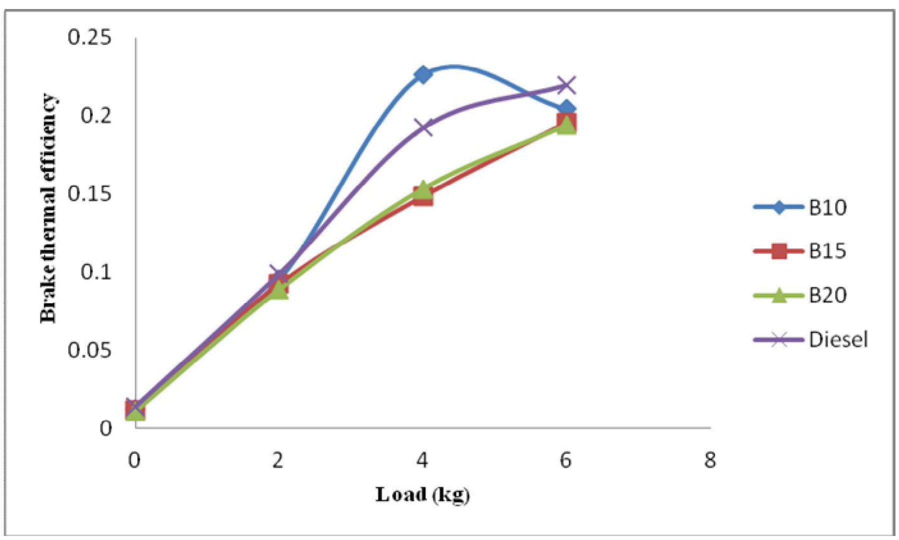

Figure 3. Variation in brake thermal efficiency with the change in load

Exhaust gas temperature (EGT). Fig. 4 illustrates the variation in exhaust gas temperature with the change in load. Exhaust gas temperature rose as the load on the engine increased. Diesel showed the least EGT among the B10, B15, B20 and D. The reason of EGT being more in the case of biodiesel blends is the presence of more oxygen atoms in the biodiesel. More oxygen atoms cause more closeness towards the complete

combustion. So, the exhaust gas temperature increased and it increased with increase in load. Moreover, as the load on the engine increased, more fuel was burnt. So, EGT increasesd continuously with rise in load.

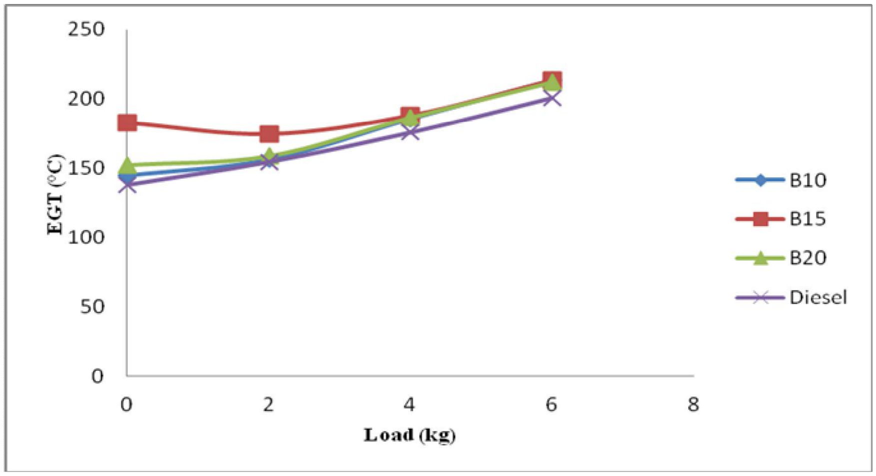

Figure 4. Variation in exhaust gas temperature with the change in load

B. Emission characteristics

Unburnt hydrocarbons(UHC). Fig. 5 illustrates the variation in amount of unburnt hydrocarbons with the change in load. At no load conditions, diesel and B10 emitted same amount of unburnt hydrocarbons whereas, maximum unburnt hydrocarbons were emitted by B15. At part and full loads, B15, B20 resulted in maximum unburnt hydrocarbons followed by B10 whereas diesel resulted in least unburnt hydrocarbons. Relatively poor atomization and lower volatility of biodiesels compared to diesel oil is responsible for this trend [10]. This trend may also be partially due to the presence of methanol in crude biodiesel which result in low cetane number value of the waste mustard biodiesel. Since unburnt hydrocarbons are the products of incomplete combustion, the lower cetane number of blend fuels results in lower tendency to form ignitable mixture, and thus, higher unburnt hydrocarbons. Higher viscosity of the waste mustard biodiesel also plays a key role in increasing the unburnt hydrocarbons in the exhaust emissions. Due to the higher viscosity, atomization of the waste mustard biodiesel does not take place properly i.e. all of the hydrocarbons present in the waste mustard biodiesel do not get completely combusted, so come out in the engine exhaust in the form of carbon particles.

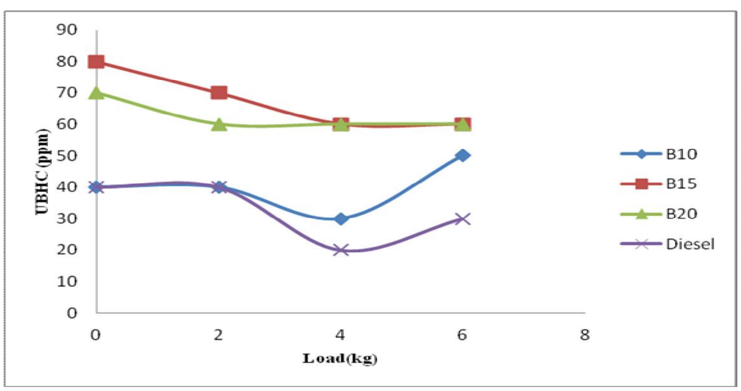

Figure 5. Variation in quantity of unburnt hydrocarbons with the change in load.

Carbon monoxide(CO). Fig. 6 illustrates the variation in amount of carbon monoxide with change in load. At no load, B10, B15 and B20 exhibited almost same amount of CO in the engine exhaust which was almost 30% less than that exhibited by diesel. After that the quantity of CO exhibited by biodiesel started to increase whereas amount of CO emission by diesel decreased. At part loads, amount of CO emissions by B10 was 14.28%, B15 was 19.1% lesser than that emitted by diesel, but B20 produced 20% more emissions than

diesel. At full load conditions, amount of CO emitted by B10, B15 and diesel was almost same whereas amount of CO emissions produced by B20 increased by 28.5% than diesel. CO is mainly produced due to incomplete combustion [11]. In case of B10 and B15, there is less amount of methyl esters present as compared to B20. So, B10 and B15 gets required amount of oxygen to get converted into CO_2, thus resulting in lesser CO as compared to diesel and B20. B20 did not get required amount of oxygen to get converted into CO_2, so resulted in more quantity of CO in the engine *exhaust*

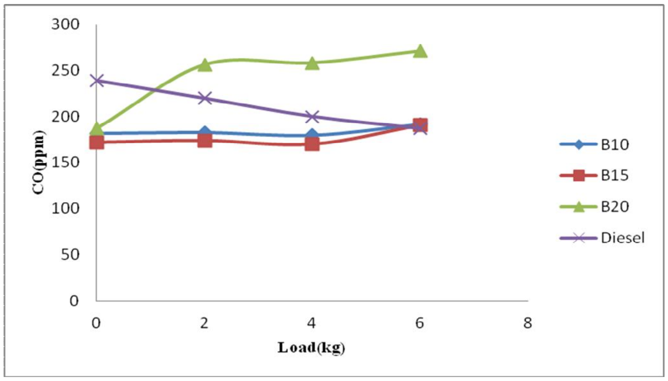

Figure 6. Variation in quantity of carbon monoxide with the change in load.

Oxides of nitrogen (NOx). Fig. 7 illustrates the variation in amount of oxides of nitrogen with change in load. At no load conditions, B10, B15 and diesel emitted almost same amount of NOx whereas B20 emitted comparatively less NOx in the exhaust. As the load on the engine increased, amount of NOx increased. It was due to the increase in temperature in the combustion chamber and at the higher temperatures [12], more amount of NOx was produced. At full load conditions, there was increase in the amount of NOx emitted by biodiesel blends and diesel. The amount of NOx produced by B10, B20 and diesel was almost same at full load conditions and the amount of NOx produced by B15 was 22.2% lesser as compared to the other blends and diesel.

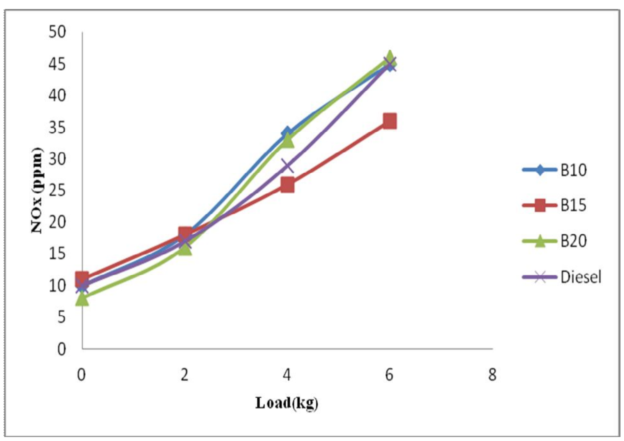

Figure 7. Variation in quantity of oxides of nitrogen with the change in load.

IV. CONCLUSIONS

At full load conditions, the brake power produced by B10 was 3.74%, B15 was 6.9% and B20 was 10.1% lesser than diesel. At full load conditions, BSFC of B10 was 10.9%, B15 was 18.23%, and B20 was 25.5% more than that of diesel. At full load conditions, brake thermal efficiency of B10, B15 and B20 was almost same but was less than diesel. B10 emitted almost same amount of CO and NOx but more unburnt hydrocarbons than that by diesel.Use of 10% blends of waste mustard biodiesel as partial diesel substitute can go a long way in conservation measure, boosting economy, reducing uncertainty of fuel availability and making more self-reliant.

Nomenclature

C.I. = Compression Ignition
BP = Brake power
BSFC = Brake specific fuel consumption
BTE = Brake thermal efficiency
EGT = Exhaust gas temperature
UBHC = Unburnt hydrocarbons
NO_x = Oxides of nitrogen
CO = Carbon monoxide
B10 = 10% biodiesel and 90% diesel
B15 = 15% biodiesel and 85% diesel
B20 = 20% biodiesel and 80% diesel
D = 100% diesel

ACKNOWLEDGMENT

The authors are grateful to Mechanical Engineering Research and Development organization (CSIR), Ludhiana (Punjab) and Thapar University, Patiala (Punjab) for extending the laboratory facilities

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